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Effect of supplemental ground flaxseed fed to beef cattle grazing summer native range on the northern Great Plains^{1,2}

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ABSTRACT: Two experiments were conducted simultaneously to evaluate the effects of supplemental ground flaxseed on site and extent of digestion and growth performance in beef cattle grazing summer native range. Six Angus heifers (initial BW 367 ± 8.0 kg) fitted with ruminal and duodenal cannulas were used in Exp. 1, and 18 Angus cross steers (initial BW 368 ± 4.6 kg) were used in Exp. 2. Cattle from both experiments were allotted to 1 of 3 individually fed treatments: grazing only (CON), grazing plus a cracked corn-soybean meal supplement fed at 0.32% of BW once daily (CRN), or grazing plus ground flaxseed fed at 0.18% of BW once daily (FLX). In Exp. 1, supplement did not affect ($P = 0.24$) masticate in vitro OM digestibility; however, between supplemented treatments, cattle fed FLX tended ($P = 0.10$) to select a lesser quality masticate than corn-fed cattle. Forage OM intake was not affected ($P = 0.17$) by supplementation, nor was there a difference ($P = 0.51$) between CRN and FLX. A quadratic ($P = 0.001$) response was observed for forage OM intake as the grazing season advanced. Duodenal and fecal OM flows were not different ($P \geq 0.42$) across treatments. Therefore, true

ruminal and total tract OM digestibilities did not differ ($P \geq 0.40$) between CON and supplement treatments, and total tract digestibility was greater ($P = 0.04$) for CRN than FLX. Total duodenal N flow did not differ ($P = 0.20$) across treatments, but responded quadratically ($P = 0.03$) with advancing season. True ruminal N digestibility was not affected by supplementation ($P \geq 0.20$). Likewise, ruminal NDF digestibility did not differ ($P = 0.29$) with supplementation, and CRN was not different ($P = 0.27$) from FLX. In Exp. 2, there was a treatment \times period interaction for forage intake ($P < 0.001$), ADG ($P = 0.001$), and feed efficiency ($P < 0.001$). Supplement did not change ($P = 0.34$) forage intake compared with CON, but it was greater for CRN than FLX ($P < 0.001$). Nevertheless, ADG was greater for supplemented steers ($P < 0.001$) compared with CON, but did not differ ($P = 0.41$) between CRN and FLX. Feed efficiency was improved ($P < 0.001$) for supplemented steers and was greater ($P = 0.01$) for FLX than CRN. Although ground flaxseed reduced digestibility compared with a corn-soybean supplement, this reduction in diet digestibility did not negatively affect the growth performance of grazing steers.

Key words: digestion, flaxseed, grazing, intake

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INTRODUCTION

Supplementing cattle during the summer grazing period can be desirable for livestock producers wishing to

increase livestock growth performance. One way to increase performance is through the provision of supplemental energy (Caton and Dhuyvetter, 1997). However, selection of appropriate supplemental energy sources in grazing animals can be difficult as forage quality changes during the grazing season (Matejovsky and Sanson, 1995). Reviews on the subject (Horn and McCollum, 1987; Caton and Dhuyvetter, 1997) have shown that performance of grazing cattle differs with supplement type and forage quality.

Use of vegetable oil or oilseeds with increased fat as supplements for grazing cattle has received little attention compared with carbohydrates. Nonetheless, in forage-based diets, feed efficiency has been shown to improve using various oils such as soybean oil (Whitney et al., 2000) or corn oil (Pavan et al., 2007) as well as whole soybeans (Albro et al., 1993). Feeding oilseeds

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offers advantages above that of oil alone because of the associated protein in the seed. Flaxseed, for example, not only has increased fat content (35% crude fat) but also CP (24% CP, DM basis) of which 67% is effectively degraded in the rumen (Mustafa et al., 2003). Limited research is available regarding the use of flaxseed for cattle grazing summer native range. Therefore, our objectives were to evaluate forage intake, site and extent of digestion, and growth performance in beef cattle supplemented with a corn-based supplement or ground flaxseed when grazing summer native rangelands on the northern Great Plains.

MATERIALS AND METHODS

All experimental procedures were reviewed and approved by the Northern Great Plains Research Laboratory Animal Care and Use committee.

Exp. 1

Animals and Diets. Six ruminally and duodenally cannulated Angus heifers (average initial BW 367 ± 8.0 kg) were rotationally grazed on rangeland at the USDA-ARS Northern Great Plains Research Laboratory (46°46' N, 100°50' W) from June 9, 2006, until September 1, 2006. The study site consisted of three 12.1-ha pastures with 2,710 kg of forage DM/ha. Major forage species included smooth brome (*Bromus inermis* Leyss.), Kentucky bluegrass (*Poa pratensis* L.), blue grama [*Bouteloua gracilis* (HBK.) Lag. Ex. Grif-fiths], Western wheatgrass [*Pascopyrum smithii* (Rybd) Löve], needle-and-thread (*Hesperostipa comata* Trin. and Rupr.), green needle grass [*Nassella viridula* (Trin.) Barkworth], and carex (*Carex filifolia* Nutt. and *Carex heliophila* Mack.). Cattle were allowed to graze each pasture for 28 d and were rotated at the end of each sampling period to the next pasture. Cattle were randomly allotted to 1 of 3 dietary treatments (2 animals per treatment): grazing only (**CON**), grazing plus cracked corn and soybean meal (65.6% cracked corn, 32.7% soybean meal, and 1.7% dried molasses) fed at 0.32% of BW on a DM basis (**CRN**), or grazing plus ground flaxseed (98.4% ground flaxseed and 1.6% dried molasses) fed at 0.18% of BW on a DM basis (**FLX**). Supplements were formulated to be isonitrogenous and isocaloric on a TDN basis and were individually fed once daily at 0730 h (Table 1). This time of feeding was chosen because cattle were typically finished with their morning grazing bout so that supplementation had minimal interference with grazing patterns (Adams, 1985). Cattle had free access to fresh water and trace mineralized blocks (American Stockman Trace Mineralized Salt, North American Salt Co., Overland Park, KS; NaCl >95.5%, Zn >3,500 mg/kg, Fe >2,000 mg/kg, Mn >1,800 mg/kg, Cu >280 mg/kg, I >100 mg/kg, Co >60 mg/kg). Cattle were weighed after a 12 h shrink at the beginning and end of each period, and

Table 1. Formulated ingredient and nutrient composition of supplement fed to beef cattle¹

Item	Supplement	
	CRN	FLX
Ingredient, %, DM		
Corn	65.6	—
Soybean meal	32.7	—
Flaxseed	—	98.4
Dried molasses	1.7	1.6
Calculated nutrient composition, % DM		
DM	94.5	91.3
N	3.8	3.5
NDF	27.1	15.3
TDN ²	69.7	69.2
Total fatty acids	21.7	3.86
16:0	1.13	0.49
18:0	0.74	0.10
18:1n-9	3.83	0.67
18:2n-6	3.71	1.98
18:3n-3	11.6	0.17

¹Cattle were allowed to graze native range pastures and were allotted to cracked corn and soybean meal (65.6% cracked corn, 32.7% soybean meal, and 1.7% dried molasses) fed at 0.32% of BW on a DM basis (CRN), or ground flaxseed (98.4% ground flaxseed and 1.6% dried molasses) fed at 0.18% of BW on a DM basis (FLX).

²Based on published values (Lardy and Anderson, 1999; NRC, 2000).

the amount of supplement fed was adjusted according to BW changes.

Sampling. Heifers were bolused with 0.44 mg of melengesterol acetate (MGA 200, Pharmacia & Upjohn Company, Kalamazoo, MI) for suppression of estrous activity throughout the experiment. Beginning on d 10, heifers were bolused with 5 g of titanium dioxide twice daily as an external marker for digesta flow (Myers et al., 2004). Starting at 0700 h on d 19, duodenal and fecal samples were collected every 6 h for 24 h then on d 20 sampling times were advanced 3 h and again collected every 6 h to represent every 3 h in a 24-h period. Duodenal and fecal samples were composited on an equal volume basis for each heifer within each sampling period. Duodenal digesta was immediately stored at -20°C , whereas fecal samples were placed in a forced-air oven at 55°C . On d 21 starting at 0700 h of each sampling period, masticate was collected from each heifer as described by Brokaw et al. (2001). Briefly, ruminal contents were completely removed, and rumens were rinsed with tap water. Heifers were allowed to graze for 60 min, and masticate was collected and immediately placed on ice. Ruminal contents were replaced, and heifers received their respective supplement. Masticate was transported to the laboratory, and 300 g of wet material was gently rinsed with 300 mL of deionized water to remove salivary contaminants. The rinsed masticate was then placed in a 55°C forced-air oven. Immediately before the 0700 h feeding on d 27, whole ruminal contents were sampled (500 mL), and 200 mL of Co-EDTA (5 g of Co; Uden et al., 1980)

was pulse-dosed intraruminally (0 h). Whole ruminal contents were collected at 3, 6, 9, 12, 15, 18, 21, 24, and 36 h postdosing (samples collected at 24 and 36 h were analyzed for Co only). Immediately after collection, ruminal pH was measured using a combination electrode (Orion Research Inc., Boston, MA), and then contents were strained through 4 layers of cheesecloth. A 10-mL aliquot of strained ruminal fluid was acidified with 0.1 mL of 7.2 *N* H₂SO₄ and immediately frozen at -20°C. In addition, an unstrained sample of whole ruminal contents was placed in a blender (Hamilton Beach/Proctor Silex, Washington, NC) with equal volume of 0.9% NaCl (wt/vol) solution and homogenized for 1 min to dislodge particulate-associated bacteria. The homogenate was then strained through 8 layers of cheesecloth and immediately frozen for subsequent bacterial isolation by differential centrifugation (Merchen et al., 1986). On d 28, 800 mL of rumen fluid was collected for analysis of in vitro OM disappearance (IVOMD) analysis of masticate and supplements.

Laboratory Analysis. All feed, microbes, duodenal digesta, and fecal samples were analyzed for DM and ash (AOAC, 1990). Nitrogen content of feed, microbes, duodenal digesta, and feces were determined using a Carlo Erba Model NA 1500 Series 2 N/C/S analyzer (CE Elantech, Lakewood, NJ). Neutral detergent fiber of feed, duodenal digesta, and feces were determined using an Ankom²⁰⁰ fiber analyzer and Ankom protocol (Ankom Technology, Fairport, NY). Masticate and supplements were analyzed for IVOMD using an Ankom Daisy^{II} Incubator and Ankom protocol. Duodenal and fecal samples were analyzed for TiO₂ (Myers et al., 2004).

Ruminal fluid samples were centrifuged at 10,000 × *g* for 20 min at 4°C, and a 2.5-mL aliquot was added to 0.5 mL of 25% metaphosphoric acid containing 2 g/L of 2-ethyl-butyric acid (Goetsch and Galyean, 1983). These samples were analyzed for concentrations of VFA using a Varian 3800 GC equipped with a 15 m × 0.533 mm (i.d.) column (Nukol, Supelco, Bellefonte, PA). Approximately 100 mg of duodenal digesta were reconstituted to 3% DM using 0.1 *N* HCl for subsequent analysis of NH₃ concentration (Hannah et al., 1991). Reconstituted duodenal digesta NH₃ concentration was determined by the phenol-hypochlorite procedure (Broderick and Kang, 1980) using a spectrophotometer (DU-640, Beckman Instruments Inc., Fullerton, CA). Ruminal fluid Co concentrations were determined using an air-plus-acetylene flame by atomic absorption spectroscopy (model 3110, Perkin Elmer Inc., Norwalk, CT). Microbial and duodenal samples were analyzed for purines as described by Zinn and Owens (1986).

Feed was analyzed for fatty acids analysis via direct transesterification with methanolic-HCl (Kucuk et al., 2001), and duodenal digesta fatty acids were analyzed using the procedures of Lake et al. (2006). Separation of fatty acid methyl esters was achieved by GLC (model CP-3800, Varian Inc., Palo Alto, CA) with a 100-m capillary column (SP-2560, Supelco, Bellefonte, PA)

and H₂ gas as a carrier gas at 1.0 mL/min for feedstuffs and 1.5 mL/min for duodenal digesta. Initial oven temperature was maintained at 120°C for 2 min and then increased to 210°C at 6°C/min and then increased to 250°C at 5°C/min. Injector temperature was 260°C, and flame ionization detector temperature was 300°C.

Calculations and Statistical Analysis. Organic matter flow was calculated by dividing the amount of Ti dosed by the concentration of Ti in the sample (duodenal and fecal). Duodenal flow of N, and NDF was calculated by multiplying nutrient concentration in duodenal OM by duodenal OM flow. The microbial purine:N ratio was calculated by dividing microbial purine content by N in bacteria (Zinn and Owens, 1986). The proportion of N flowing at the small intestine of microbial origin was calculated by dividing the purine:N ratio of duodenal digesta by the purine:N ratio of microbial isolates. Microbial OM flowing to the duodenum was calculated by dividing duodenal microbial N flow by microbial N as a percentage of OM. Duodenal non-ammonia, nonmicrobial N was calculated by subtracting duodenal microbial N and ammonia N flow from total duodenal N flow. True ruminal digestibility was calculated based on the amount of nutrient ingested subtracted from the amount present at the small intestine without microbial nutrient contributions. Ruminal fluid passage rate was calculated by regression of the natural logarithm of Co concentration against time after dosing (Uden et al., 1980). All data were analyzed using the MIXED model (SAS Inst. Inc., Cary, NC) as a split-plot in a completely randomized design. The model used was

$$Y_{ijk} = \mu + T_i + C_{j(i)} + P_k + TP_{ik} + e_{ijk},$$

where T_i is the *i*th treatment, $C_{j(i)}$ is the *j*th cow in the *i*th treatment, P_k is the *k*th period, TP_{ik} is the interaction between treatment and period, Y_{ijk} denotes the value of the variable of interest for cow *i* on treatment *j* during period *k*, and μ is the overall mean. Single degree of freedom orthogonal contrasts were used to compare effects of CON vs. supplements (CRN and FLX), as well as CRN vs. FLX, and sampling period effects were tested using orthogonal polynomial contrasts (Steel and Torrie, 1980). Differences between treatments were considered significant at $P < 0.05$ and a trend at $P < 0.10$.

Exp. 2

Animals and Diets. Eighteen Angus crossed steers (average initial BW 368 ± 4.6 kg) were rotationally grazed on typical rangeland at the USDA-ARS Northern Great Plains Research Laboratory (46°46' N, 100°50' W) from June 9, 2006, until September 1, 2006. The study site and dietary treatments (6 animals per treatment) were the same as described in Exp. 1. Starting on d 19 of each period, steers were bolused with 5 g of titanium dioxide twice daily. Cattle had free access

Table 2. Effects of supplemental ground flaxseed on the quality of masticate collected from heifers grazing summer native range on the northern Great Plains (Exp. 1)

Item	Treatment ¹				<i>P</i> -value ³		Sampling period ⁴				<i>P</i> -value ⁶		Trt × Pd ⁷
	CON	CRN	FLX	SEM ²	1	2	1	2	3	SEM ⁵	Linear	Quadratic	
OM, % of DM	91.1	90.6	91.0	0.34	0.54	0.37	90.9	91.8	89.9	0.34	0.06	0.01	0.59
N, % of OM	1.28	1.27	1.25	0.03	0.55	0.52	1.43	1.03	1.34	0.02	0.04	<0.001	0.01
NDF, % of OM	80.3	80.8	81.7	0.64	0.29	0.39	79.7	84.6	78.6	0.69	0.31	0.001	0.31
IVOMD, ⁸ % of OM	71.4	71.3	68.5	0.87	0.24	0.11	71.9	64.8	74.6	0.92	0.09	<0.001	0.53
Total fatty acid, % of OM	1.12	1.17	1.17	0.03	0.14	1.0	1.26	0.99	1.21	0.03	0.34	0.001	0.96

¹Cattle were allowed to graze native range pastures and were allotted to 1 of 3 dietary treatments: grazing only (CON); cracked corn and soybean meal (65.6% cracked corn, 32.7% soybean meal, and 1.7% dried molasses) fed at 0.32% of BW on a DM basis (CRN); or ground flaxseed (98.4% ground flaxseed and 1.6% dried molasses) fed at 0.18% of BW on a DM basis (FLX).

²n = 2.

³Treatment contrasts: 1: CON vs. CRN and FLX; 2: CRN vs. FLX.

⁴Sampling periods: 1 = June 9 to July 7, 2006; 2 = July 8 to August 4, 2006; 3 = August 5 to September 1, 2006.

⁵n = 6.

⁶Sampling period contrasts.

⁷Treatment × sampling period interaction.

⁸IVOMD = in vitro OM disappearance.

to fresh water and trace mineralized blocks (American Stockman, North American Salt Co.). Cattle were weighed after a 12-h shrink at the beginning and end of each period, and the amount of supplement fed was adjusted according to BW changes.

Sampling and Laboratory Analysis. Starting on d 23, fecal samples (50 mL, wet basis) were obtained from steers twice daily until the end of the period. Fecal samples were composited by animal, dried in a 55°C oven, and ground through a 1-mm screen (Wiley mill, Thomas Hill and Sons, Philadelphia, PA). All fecal samples were analyzed as described in Exp. 1.

Calculations and Statistical Analysis. Forage intake was calculated based on masticate quality (Brokaw et al., 2001). All data were analyzed using the MIXED model of SAS as a split-plot in a completely random design. Supplementation was used as the main plot tested against animal within treatment (error a) and the effect of sampling period, and the treatment × sampling period interaction was the subplot tested against residual error (error b). Single degree of freedom orthogonal contrasts were used to compare effects of CON vs. supplements (CRN and FLX), as well as CRN vs. FLX, and sampling period effects were tested using orthogonal polynomial contrasts (Steel and Torrie, 1980). Therefore, main effects will also be presented. In addition, because of scale malfunction steer performance data from period 2 were dropped from the model; therefore, the statistical model only includes sampling periods 1 and 3, which are referred to in Table 11 as early and late summer.

RESULTS

Exp. 1

Masticate Quality. In Exp. 1, there were no treatment × sampling period interactions for masticate OM, NDF, IVOMD, or total fatty acid ($P \geq 0.31$; data not

shown). However, there was a treatment × sampling period interaction ($P = 0.01$) for masticate N due in part to the lack of differences across treatments in sampling period 1. However, during sampling period 2, CRN had the least masticate N, whereas masticate collected in period 3 had the greatest masticate N concentration (data not shown). Dietary treatment did not influence ($P \geq 0.29$) masticate quality with the exception of IVOMD, where flax-fed cattle tended ($P = 0.10$) to select a lesser quality masticate than CRN (Table 2). Sampling period influenced ($P \leq 0.01$) masticate OM, N, NDF, IVOMD, and total fatty acid with sampling period 2 having the least N, IVOMD, and total fatty acid concentrations, whereas NDF and OM were greatest compared with sampling period 1 or 3.

Ruminal Fermentation. In Exp. 1, there were no treatment × period interactions ($P \geq 0.06$) for ruminal pH, fluid passage rate, total VFA, or molar proportions of acetate, propionate, butyrate, valerate, or isobutyrate. However, a treatment × sampling period interaction was observed ($P < 0.001$) for the molar proportions of isovalerate (data not shown). There were treatment × hour interactions ($P \leq 0.02$) for total VFA, acetate, propionate, isobutyrate, and isovalerate (data not shown). The molar proportions of propionate, isobutyrate, and isovalerate at 3 h transiently increased, causing differences to occur across treatment and time, whereas molar proportions of acetate decreased at 3 h. Total VFA did not differ across treatments at 0 h; however, from 3 to 18 h FLX was less than CON and CRN, but CON did not differ from CRN. Ruminal pH did not differ ($P = 0.78$) with supplementation, yet feeding a corn-based supplement reduced ruminal pH ($P = 0.04$) more than feeding ground flaxseed (Table 3). Total ruminal VFA concentration tended to be less ($P = 0.08$) for supplemented cattle, and CRN was greater ($P = 0.01$) than FLX. Molar proportions of acetate were less ($P < 0.001$) for supplemented treatments, with corn-fed cattle less ($P = 0.03$) than fat-supplemented cattle. No

Table 3. Effects of supplemental ground flaxseed on the ruminal pH, fluid passage rate, and VFA in beef heifers grazing summer native range on the northern Great Plains (Exp. 1)

Item	Treatment ¹				P-value ³		Sampling period ⁴				P-value ⁶		Trt × Pd ⁷
	CON	CRN	FLX	SEM ²	1	2	1	2	3	SEM ⁵	Linear	Quadratic	
Ruminal pH	6.01	5.89	6.19	0.09	0.78	0.04	6.02	6.06	6.01	0.09	0.97	0.43	0.39
Ruminal fluid passage rate, %/h	10.7	9.55	9.13	0.68	0.15	0.68	10.7	7.62	11.1	0.68	0.69	0.01	0.27
Ruminal total VFA, mM	76.1	75.9	61.8	3.1	0.08	0.01	75.2	68.0	70.5	3.1	0.49	0.18	0.98
Ruminal VFA, mol/100 mol													
Acetate	73.7	71.4	72.4	0.3	0.001	0.03	72.1	73.0	72.4	0.3	0.23	0.04	0.44
Propionate	15.4	15.2	15.6	0.3	0.89	0.41	15.5	15.2	15.5	0.3	0.91	0.29	0.88
Butyrate	9.35	11.4	10.0	0.3	0.002	0.01	10.7	10.0	10.1	0.3	0.08	0.30	0.78
Isobutyrate	0.58	0.67	0.72	0.02	0.004	0.19	0.54	0.66	0.77	0.02	<0.001	1.0	0.12
Isovalerate	0.49	0.68	0.45	0.04	0.004	0.56	0.53	0.59	0.69	0.04	0.01	0.31	0.30
Valerate	0.55	0.63	0.63	0.00	<0.001	0.64	0.73	0.53	0.55	0.00	<0.001	<0.001	0.03

¹Cattle were allowed to graze native range pastures and were allotted to 1 of 3 dietary treatments: grazing only (CON); cracked corn and soybean meal (65.6% cracked corn, 32.7% soybean meal, and 1.7% dried molasses) fed at 0.32% of BW on a DM basis (CRN); or ground flaxseed (98.4% ground flaxseed and 1.6% dried molasses) fed at 0.18% of BW on a DM basis (FLX).

²n = 2.

³Treatment contrasts: 1: CON vs. CRN and FLX; 2: CRN vs. FLX.

⁴Sampling periods: 1 = June 9 to July 7, 2006; 2 = July 8 to August 4, 2006; 3 = August 5 to September 1, 2006.

⁵n = 6.

⁶Sampling period contrasts.

⁷Treatment × sampling period interaction.

differences ($P \geq 0.41$) were observed across treatments for molar proportions of propionate. Molar proportions of butyrate were greater ($P = 0.002$) for supplemented cattle compared with unsupplemented controls, with CRN being greater than FLX ($P = 0.01$).

OM, N, and NDF Intake and Digestibility.

There was not a treatment × sampling period interaction ($P \geq 0.16$) for any of the variables measured for OM. Forage or total OM intake did not differ ($P \geq 0.17$) across treatments (Table 4). Intakes were less (quadratic, $P = 0.001$) during sampling period 2 compared with sampling period 1 or 3. Dietary treatment did not

influence ($P \geq 0.42$) duodenal OM flow. Nevertheless, microbial OM flow to the duodenum was greater ($P = 0.02$) for cattle receiving supplemented compared with unsupplemented cattle. True ruminal OM digestibility did not differ ($P = 0.58$) with supplemental energy, yet tended to be greater ($P = 0.10$) for CRN than FLX.

There tended to be a treatment × sampling period interaction ($P = 0.06$) for N intake with corn-fed heifers having the greatest N intake for sampling periods 1 and 2 and no differences being observed across treatments during sampling period 3. Total duodenal N flow did not differ ($P = 0.20$) across treatments; likewise,

Table 4. Effects of supplemental ground flaxseed on intake, flow, and site and extent of digestion of OM in beef heifers grazing summer native range on the northern Great Plains (Exp. 1)

Item	Treatment ¹				P-value ³		Sampling period ⁴				P-value ⁶		Trt × Pd ⁷
	CON	CRN	FLX	SEM ²	1	2	1	2	3	SEM ⁵	Linear	Quadratic	
Intake, g/d													
Forage	7,781	7,018	6,542	457.7	0.17	0.51	6,304	5,708	9,329	346.1	<0.001	0.001	0.16
Total	7,781	8,099	7,170	452.2	0.81	0.24	6,838	6,277	9,936	341.2	<0.001	0.001	0.18
Duodenal flow, g/d													
Total	2,763	2,632	2,894	198.5	1.0	0.42	2,467	2,644	3,178	123.6	<0.001	0.04	0.19
Microbial	614.0	695.7	771.9	30.7	0.02	0.13	703.2	587.0	791.5	28.6	0.06	0.003	0.41
True ruminal digestibility, % of intake	71.3	75.8	69.7	1.87	0.58	0.10	73.7	67.2	76.0	1.49	0.24	0.003	0.26
Total tract digestibility, % of intake	71.4	74.6	70.3	0.84	0.40	0.04	73.5	67.1	75.8	0.78	0.08	<0.001	0.18

¹Cattle were allowed to graze native range pastures and were allotted to 1 of 3 dietary treatments: grazing only (CON); cracked corn and soybean meal (65.6% cracked corn, 32.7% soybean meal, and 1.7% dried molasses) fed at 0.32% of BW on a DM basis (CRN); or ground flaxseed (98.4% ground flaxseed and 1.6% dried molasses) fed at 0.18% of BW on a DM basis (FLX).

²n = 2.

³Treatment contrasts: 1: CON vs. CRN and FLX; 2: CRN vs. FLX.

⁴Sampling periods: 1 = June 9 to July 7, 2006; 2 = July 8 to August 4, 2006; 3 = August 5 to September 1, 2006.

⁵n = 6.

⁶Sampling period contrasts.

⁷Treatment × sampling period interaction.

Table 5. Effects of supplemental ground flaxseed on intake, flow, and site and extent of digestion of N in beef heifers grazing summer native range on the northern Great Plains (Exp. 1)

Item	Treatment ¹			SEM ²	P-value ³		Sampling period ⁴			SEM ⁵	P-value ⁶		Trt × Pd ⁷
	CON	CRN	FLX		1	2	1	2	3		Linear	Quadratic	
Intake, g/d	101.8	131.3	107.0	7.47	0.15	0.10	110.3	80.8	149.0	5.07	<0.001	0.06	0.06
Duodenal flow, g/d													
Total	99.2	113.4	107.8	5.78	0.20	0.54	105.5	99.4	115.4	4.17	0.06	0.03	0.70
Microbial	57.9	63.8	69.8	3.55	0.13	0.32	65.4	55.2	70.9	2.72	0.13	0.003	0.26
NH ₃	4.76	8.82	7.65	0.91	0.02	0.40	7.27	6.35	7.61	0.57	0.39	0.01	0.07
NMNAN ⁸	36.5	40.7	30.3	4.9	0.88	0.23	32.8	37.9	3.9	3.2	0.14	0.19	0.27
True ruminal digestibility, % of intake	58.7	67.8	70.2	5.23	0.20	0.77	69.8	51.5	75.3	3.89	0.24	0.001	0.31
Total tract digestibility, % of intake	61.0	69.3	62.2	0.8	0.02	0.01	67.8	54.2	70.5	1.10	0.17	<0.001	0.01

¹Cattle were allowed to graze native range pastures and were allotted to 1 of 3 dietary treatments: grazing only (CON); cracked corn and soybean meal (65.6% cracked corn, 32.7% soybean meal, and 1.7% dried molasses) fed at 0.32% of BW on a DM basis (CRN); or ground flaxseed (98.4% ground flaxseed and 1.6% dried molasses) fed at 0.18% of BW on a DM basis (FLX).

²n = 2.

³Treatment contrasts: 1: CON vs. CRN and FLX; 2: CRN vs. FLX.

⁴Sampling periods: 1 = June 9 to July 7, 2006; 2 = July 8 to August 4, 2006; 3 = August 5 to September 1, 2006.

⁵n = 6.

⁶Sampling period contrasts.

⁷Treatment × sampling period interaction.

⁸NMNAM: nonmicrobial, nonammonia N.

microbial N flow ($P = 0.13$) was not affected (Table 5). Furthermore, duodenal NH₃ supply was greater ($P = 0.02$) for CRN and FLX compared with CON. Duodenal nonammonia, nonmicrobial N did not differ ($P = 0.23$). True ruminal N digestibility was not different across treatments ($P \geq 0.20$), yet total tract N digestibility was greater ($P = 0.01$) for supplemented cattle and CRN was greater than FLX ($P = 0.01$).

There were no treatment × sampling period interactions ($P \geq 0.18$) for NDF intake or digestion. Likewise, NDF intake, and ruminal and total tract NDF digestibility did not differ ($P \geq 0.21$) among treatments (Table 6). However, there was a quadratic response ($P \leq 0.01$) for all NDF variables measured across sampling period with values being the least during period 2.

Fatty Acid Intake, Duodenal Supply, and Postruminal Disappearance. There was a treatment × sampling period interaction ($P = 0.01$) for intake of linolenic acid (18:3n-3) with no difference being observed between CON and CRN during sampling period 1 and CRN being greater than CON during sampling period 3. Intake of 16:0 did not differ ($P = 0.16$) when cattle were supplemented, and no differences were observed ($P = 0.96$) between CRN and FLX (Table 7). Dietary consumption of 18:0 increased ($P = 0.03$) with supplementation, and the provision of ground flaxseed increased dietary supply ($P = 0.04$) of 18:0. Nevertheless, intake of SFA did not differ ($P = 0.26$) between supplemented treatments. Intake of 18:2n-6 was greater ($P < 0.001$) for supplemented cattle, whereas no differ-

Table 6. Effects of supplemental ground flaxseed on intake, and site and extent of digestion of NDF in beef heifers grazing summer native range on the northern Great Plains (Exp. 1)

Item	Treatment ¹			SEM ²	P-value ³		Sampling period ⁴			SEM ⁵	P-value ⁶		Trt × Pd ⁷
	CON	CRN	FLX		1	2	1	2	3		Linear	Quadratic	
Intake, g/d	6,926	6,461	6,185	507.8	0.40	0.72	5,120	4,941	9,512	372.4	<0.001	0.001	0.23
Ruminal NDF digestibility, % of intake	74.8	79.1	75.8	1.71	0.29	0.27	75.8	72.1	81.9	1.53	0.02	0.01	0.23
Total tract digestibility, % of intake	73.4	74.4	72.4	0.89	0.98	0.21	72.4	67.6	80.1	0.74	<0.001	<0.001	0.18

¹Cattle were allowed to graze native range pastures and were allotted to 1 of 3 dietary treatments: grazing only (CON); cracked corn and soybean meal (65.6% cracked corn, 32.7% soybean meal, and 1.7% dried molasses) fed at 0.32% of BW on a DM basis (CRN); or ground flaxseed (98.4% ground flaxseed and 1.6% dried molasses) fed at 0.18% of BW on a DM basis (FLX).

²n = 2.

³Treatment contrasts: 1: CON vs. CRN and FLX; 2: CRN vs. FLX.

⁴Sampling periods: 1 = June 9 to July 7, 2006; 2 = July 8 to August 4, 2006; 3 = August 5 to September 1, 2006.

⁵n = 6.

⁶Sampling period contrasts.

⁷Treatment × sampling period interaction.

Table 7. Effects of supplemental ground flaxseed on intake (g/d) of fatty acids in beef heifers grazing summer native range on the northern Great Plains (Exp. 1)

Item	Treatment ¹				<i>P</i> -value ³		Sampling period ⁴				<i>P</i> -value ⁶		Trt × Pd ⁷
	CON	CRN	FLX	SEM ²	1	2	1	2	3	SEM ⁵	Linear	Quadratic	
16:0	21.5	24.8	24.7	1.36	0.15	0.96	22.9	18.9	29.2	1.1	0.003	0.001	0.30
18:0	5.9	7.0	9.1	0.9	0.03	0.04	5.9	7.0	9.1	0.9	0.04	0.64	0.80
18:1n-9	6.1	12.9	29.3	0.6	<0.001	<0.001	17.2	12.5	18.6	0.45	0.04	<0.001	0.08
18:2n-6	15.0	36.7	35.9	1.18	<0.001	0.69	31.9	19.9	35.9	1.1	0.04	<0.001	0.83
18:3n-3	14.0	14.0	81.3	1.4	<0.001	<0.001	37.0	26.5	45.7	1.1	<0.001	<0.001	0.01
SFA	26.2	31.3	35.4	2.1	0.06	0.26	28.8	25.9	38.2	1.7	0.01	0.01	0.60
MUFA	6.1	12.9	29.3	0.6	<0.001	<0.001	17.2	12.5	18.6	0.4	0.04	<0.001	0.08
PUFA	29.0	50.7	117.2	2.5	<0.001	<0.001	68.9	46.4	81.6	2.1	0.003	<0.001	0.12
TUFA ⁸	35.1	63.6	146.5	3.1	<0.001	<0.001	86.0	58.9	100.2	2.6	0.05	<0.001	0.11
Total	88.5	126.3	211.3	6.6	0.002	0.002	140.7	107.5	177.8	5.6	0.002	<0.001	0.48

¹Cattle were allowed to graze native range pastures and were allotted to 1 of 3 dietary treatments: grazing only (CON); cracked corn and soybean meal (65.6% cracked corn, 32.7% soybean meal, and 1.7% dried molasses) fed at 0.32% of BW on a DM basis (CRN); or ground flaxseed (98.4% ground flaxseed and 1.6% dried molasses) fed at 0.18% of BW on a DM basis (FLX).

² $n = 2$.

³Treatment contrasts: 1: CON vs. CRN and FLX; 2: CRN vs. FLX.

⁴Sampling periods: 1 = June 9 to July 7, 2006; 2 = July 8 to August 4, 2006; 3 = August 5 to September 1, 2006.

⁵ $n = 6$.

⁶Sampling period contrasts.

⁷Treatment × sampling period interaction.

⁸TUFA = total unsaturated fatty acids.

ences were observed ($P = 0.69$) between CRN and FLX. Intake of 18:1n-9 and 18:3n-3 increased ($P < 0.001$). Therefore, intake of unsaturated fatty acids (MUFA, PUFA, and total unsaturated fatty acids) increased for supplemented cattle ($P < 0.001$) and FLX ($P < 0.001$) compared with CRN. Sampling period influenced fatty acid intake with a quadratic response with time being observed ($P \leq 0.01$) for all fatty acids with the exception of 18:0 ($P = 0.64$).

There was a treatment × sampling period interaction ($P \leq 0.05$) for duodenal flow of 18:1n-9 and 20:3n-6. The provision of supplements increased the duodenal supply ($P \geq 0.02$) for 10 of the 28 fatty acids identified (Table 8). Likewise, the addition of dietary fat from ground flaxseed increased ($P \geq 0.04$) intestinal supply of 10 of the 28 fatty acids identified above that of corn-fed cattle. Most notable was 18:3n-3, which increased ($P = 0.01$) with either corn or flaxseed being fed, and flaxseed provided 11.7 g more intestinal 18:3n-3 per day ($P = 0.001$) than corn. Duodenal flow of PUFA increased ($P = 0.01$) with supplementation and was greater ($P < 0.002$) in FLX than CRN. Some PUFA of interest that were increased with flaxseed supplementation over corn would be 18:2n-6 ($P = 0.002$), CLA ($P < 0.001$), and 18:3n-3 ($P < 0.001$). Total duodenal fatty acid supply (g/d) increased with supplements ($P = 0.01$), with FLX being greater than CRN ($P = 0.003$). Most fatty acids reaching the small intestine increased in concentration (mg/g of DM; linear, $P < 0.01$) as the grazing season progressed.

A treatment × sampling period interaction was observed ($P = 0.01$) for postruminal disappearance (% of duodenal supply) of 18:3n-3, with FLX being greater during period 1 and 2 than 3, whereas no treatment differences were observed across supplemented treatments

in period 3 (data not shown). Sampling period alone did not influence ($P = 0.28$) postruminal disappearance of most fatty acids (Table 9). Postruminal disappearance of PUFA, 18:2n-6, and 18:3n-3 increased ($P \leq 0.05$) with supplementation. However, only postruminal disappearance of 18:3n-3 ($P = 0.02$) differed between CRN and FLX, with FLX being greater. Linear increases in postruminal disappearance ($P \leq 0.04$) were observed for 18:0, 18:1n-9, and MUFA. Postruminal disappearance of total fatty acids did not differ across treatments ($P = 0.38$), yet tended to increase (linear, $P = 0.074$) as the grazing season progressed.

Exp. 2

OM, NDF, N Intake, and Digestibility. There was a treatment × sampling period interaction ($P < 0.001$) for OM, NDF, and N intake as well as apparent total tract OM, NDF, and N digestibility (data not shown). These differences were due to a change in magnitude of differences between CON and CRN. The provision of supplemental energy increased total OM and N intake ($P \leq 0.001$), whereas NDF intake did not differ ($P = 0.48$) due to supplementation (Table 10). Forage OM intake was reduced with FLX ($P < 0.001$) when compared with CRN. In addition, intakes of total OM, NDF, and N all differed ($P < 0.001$) when CRN and FLX were compared with FLX consistently consuming less than CON or CRN. Intake of OM, NDF, and N was influenced by sampling period ($P < 0.001$), with sampling period 2 intakes being less than either sampling period 1 or 3.

Total tract digestibility of OM was not affected by supplementation ($P = 0.17$), but NDF and N digestibility were increased ($P < 0.001$). In addition, total tract

digestibility of OM, NDF, and N were less ($P < 0.001$) for FLX than CRN-supplemented cattle. Sampling period 2 had the least ($P \leq 0.05$) total tract OM digestibility when compared with sampling period 1 or 3.

Growth Performance. A treatment \times sampling period interaction was observed ($P \leq 0.003$) for total BW gain, ADG, and G:F. Initial BW did not differ ($P = 0.92$); however, final BW was greater ($P = 0.001$) for cattle supplemented with additional energy and no differences were observed ($P = 0.50$) between CRN and FLX (data not shown). Similarly, cattle receiving supplement had greater overall BW gain ($P < 0.001$) and ADG ($P = 0.001$), whereas no differences were observed ($P \geq 0.41$) between supplemented treatments

(Table 11). Supplementation increased G:F ($P = 0.01$) with the provision of flaxseed increasing ($P < 0.001$) the G:F over corn-fed cattle. Cattle had greater ADG and G:F ($P \leq 0.004$) during late compared with early summer.

DISCUSSION

The impact of protein supplementation on masticate composition has been investigated previously (Judkins et al., 1985; Grings et al., 1994) with no effect reported. Likewise, Brokaw et al. (2001) did not observe any differences in the quality of masticate selected with the exception of crude fat concentration when beef heifers

Table 8. Effects of supplemental ground flaxseed on duodenal flow (g/d) of fatty acids in beef heifers grazing summer native range on the northern Great Plains (Exp. 1)

Item	Treatment ¹			SEM ²	P-value ³		Sampling period ⁴			SEM ⁵	P-value ⁶		Trt \times Pd ⁷
	CON	CRN	FLX		1	2	1	2	3		Linear	Quadratic	
14:0	0.11	0.07	0.11	0.04	0.41	0.26	0.13	0.07	0.09	0.02	0.26	0.17	0.67
14:1	1.34	1.51	1.56	0.10	0.18	0.72	1.23	1.43	1.75	0.07	<0.001	0.38	0.15
15:0	1.91	2.13	2.07	0.16	0.38	0.8	1.81	1.93	2.37	0.10	<0.001	0.05	0.20
15:1	0.26	0.30	0.36	0.03	0.10	0.21	0.23	0.30	0.38	0.03	0.01	0.88	0.54
16:0	15.6	19.2	27.3	1.6	0.03	0.04	17.8	21.2	23.1	0.98	<0.001	0.16	0.14
16:1	0.52	0.61	0.56	0.08	0.55	0.70	0.49	0.57	0.63	0.06	0.05	0.90	0.26
17:0	0.90	0.87	0.79	0.14	0.72	0.72	0.81	0.72	1.02	0.09	0.01	0.01	0.37
17:1	0.43	0.0	0.13	0.25	0.32	0.73	0.53	0.0	0.02	0.25	0.20	0.39	0.55
18:0	34.3	54.1	186.4	11.0	0.001	0.001	81.0	91.1	102.6	6.5	<0.001	0.76	0.19
18:1 <i>trans</i> 11	0.02	0.0	1.14	0.11	0.03	0.001	0.26	0.34	0.56	0.10	0.06	0.60	0.10
18:1 <i>n</i> -9	2.5	3.4	9.1	0.4	0.005	0.002	5.0	4.0	6.0	0.3	0.01	0.001	0.01
18:2 <i>n</i> -6	2.8	3.7	7.2	0.5	0.02	0.01	4.0	4.4	5.3	0.34	0.01	0.39	0.70
20:0	2.1	2.3	2.9	0.3	0.21	0.18	1.7	2.5	3.1	0.2	0.17	0.14	0.33
20:1	0.01	0.00	0.00	0.01	0.21	1.0	0.01	0.0	0.0	0.01	0.27	0.51	0.48
18:3 <i>n</i> -3	1.3	1.2	12.9	0.5	0.01	0.001	4.2	5.1	6.0	0.7	0.13	0.98	0.69
CLA ⁸	0.04	0.06	0.50	0.03	0.01	0.003	0.21	0.19	0.21	0.03	0.82	0.41	0.07
21:0	0.17	0.20	0.23	0.01	0.12	0.21	0.12	0.20	0.27	0.01	<0.001	0.45	0.12
20:2	0.01	0.00	0.18	0.01	0.01	0.001	0.05	0.08	0.063	0.01	0.52	0.13	0.07
22:0	2.3	2.5	2.8	0.2	0.18	0.35	1.5	2.4	3.5	0.2	<0.001	0.57	0.75
20:3 <i>n</i> -6	0.02	0.18	0.08	0.04	0.08	0.13	0.10	0.11	0.06	0.02	0.04	0.04	0.05
22:1	0.12	0.14	0.11	0.07	0.89	0.77	0.26	0.05	0.07	0.05	0.02	0.07	0.50
20:3 <i>n</i> -3	0.87	0.88	1.25	0.10	0.20	0.08	0.39	1.20	1.41	0.11	0.001	0.09	0.69
20:4	0.41	0.39	0.77	0.16	0.44	0.20	0.14	0.71	0.72	0.24	0.17	0.41	0.96
23:0	0.56	0.58	0.71	0.06	0.29	0.22	0.44	0.62	0.79	0.04	<0.001	0.98	0.16
22:2	0.09	0.05	0.24	0.03	0.16	0.01	0.16	0.14	0.08	0.03	0.22	0.73	0.44
24:0	3.3	3.5	3.7	0.2	0.27	0.57	2.5	3.5	4.5	0.2	<0.001	0.93	0.51
20:5	0.04	0.08	0.30	0.02	0.004	0.003	0.14	0.17	0.12	0.02	0.49	0.13	0.24
24:1	0.31	0.29	0.25	0.03	0.34	0.48	0.27	0.27	0.30	0.02	0.40	0.69	0.66
Other	48.5	35.3	66.0	2.8	0.57	0.005	53.3	44.1	52.4	1.8	0.54	<0.001	<0.001
SFA	58	82	223	13	0.01	0.003	105	121	137	8	<0.001	0.89	0.34
MUFA	3.0	2.8	4.1	0.24	0.19	0.03	3.3	3.0	3.7	0.3	0.26	0.17	0.60
PUFA	5.1	6.1	22.7	1.1	0.01	0.002	9.3	11.3	13.3	1.0	0.03	0.94	0.64
TUFA ⁹	8.1	9.0	26.8	1.2	0.01	0.002	12.5	14.3	17.0	1.0	0.01	0.72	0.48
Total	117	130	325	15	0.01	0.003	176	184	213	9	<0.001	0.05	0.06

¹Cattle were allowed to graze native range pastures and were allotted to 1 of 3 dietary treatments: grazing only (CON); cracked corn and soybean meal (65.6% cracked corn, 32.7% soybean meal, and 1.7% dried molasses) fed at 0.32% of BW on a DM basis (CRN); or ground flaxseed (98.4% ground flaxseed and 1.6% dried molasses) fed at 0.18% of BW on a DM basis (FLX).

² $n = 2$.

³Treatment contrasts: 1: CON vs. CRN and FLX; 2: CRN vs. FLX.

⁴Sampling periods: 1 = June 9 to July 7, 2006; 2 = July 8 to August 4, 2006; 3 = August 5 to September 1, 2006.

⁵ $n = 6$.

⁶Sampling period contrasts.

⁷Treatment \times sampling period interaction.

⁸CLA = 18:2*cis*-9 *trans*-11 + 18:2*trans*-10 *cis*-12.

⁹TUFA = total unsaturated fatty acids.

Table 9. Effects of supplemental ground flaxseed on postruminal disappearance (% of duodenal flow) of fatty acids in beef heifers grazing summer native range on the northern Great Plains (Exp. 1)

Item	Treatment ¹				P-value ³		Sampling period ⁴				P-value ⁶		Trt × Pd ⁷
	CON	CRN	FLX	SEM ²	1	2	1	2	3	SEM ⁵	Linear	Quadratic	
16:0	73.5	77.7	78.3	1.8	0.13	0.84	76.5	74.9	78.1	1.6	0.46	0.23	0.58
18:0	90.7	92.2	91.3	1.0	0.45	0.52	93.5	93.0	87.7	1.0	0.01	0.09	0.17
18:1n-9	70.4	71.5	80.1	2.4	0.16	0.08	79.1	76.5	66.3	2.6	0.02	0.29	0.87
18:2n-6	67.8	86.2	90.5	5.5	0.05	0.61	80.6	81.3	82.6	3.6	0.52	0.91	0.15
18:3n-3	77.4	87.1	95.9	1.3	0.003	0.02	88.3	85.9	86.2	1.3	0.28	0.41	0.01
SFA	82.3	84.2	83.9	1.2	0.33	0.85	83.4	82.1	84.9	1.6	0.58	0.39	0.49
MUFA	21.6	38.3	45.9	12.1	0.26	0.69	49.2	50.3	6.3	8.1	0.001	0.01	0.89
PUFA	64.2	84.1	83.4	5.0	0.05	0.93	73.6	84.0	57.5	6.1	0.03	0.12	0.17
TUFA ⁸	55.1	74.1	75.1	6.2	0.08	0.92	65.7	66.5	72.1	4.5	0.22	0.58	0.73
Total	74.8	72.7	72.3	1.8	0.38	0.91	71.0	68.4	80.3	2.5	0.06	0.08	0.93

¹Cattle were allowed to graze native range pastures and were allotted to 1 of 3 dietary treatments: grazing only (CON); cracked corn and soybean meal (65.6% cracked corn, 32.7% soybean meal, and 1.7% dried molasses) fed at 0.32% of BW on a DM basis (CRN); or ground flaxseed (98.4% ground flaxseed and 1.6% dried molasses) fed at 0.18% of BW on a DM basis (FLX).

²n = 2.

³Treatment contrasts: 1: CON vs. CRN and FLX; 2: CRN vs. FLX.

⁴Sampling periods: 1 = June 9 to July 7, 2006; 2 = July 8 to August 4, 2006; 3 = August 5 to September 1, 2006.

⁵n = 6.

⁶Sampling period contrasts.

⁷Treatment × sampling period interaction.

⁸TUFA = total unsaturated fatty acids.

grazing summer pasture received supplemental cracked corn or soybean oil. Supplemented heifers selected forage greater in fat than unsupplemented controls. Hess et al. (1994) reported that cattle grazing intermediate wheatgrass and supplemented with corn gluten meal and wheat bran selected masticate greater in IVOMD than cattle receiving no supplement, alfalfa hay, or cottonseed meal. It is unclear why cattle fed flaxseed tended to select for lesser quality masticate compared with unsupplemented or corn-supplemented cattle. What is also unclear is why forage quality was decreased during

sampling period 2 than period 1 or 3. A linear decrease in forage quality was expected based on previous reports (Johnson et al., 1995; Schauer et al., 2004). A quadratic response in forage quality across the summer months has been reported previously (Patton et al., 2000) in the northern Great Plains.

The treatment × hour interaction observed for molar proportions of ruminal acetate was due to a brief depression in ruminal concentrations of acetate shortly after morning supplementation for FLX compared with more consistent values over time for CRN or CON, and

Table 10. Effects of supplemental ground flaxseed on the apparent total tract OM, NDF, and N disappearance in steers grazing summer native range on the northern Great Plains (Exp. 2)

Item	Treatment ¹				P-value ³		Sampling period ⁴				P-value ⁶		Trt × Pd ⁷
	CON	CRN	FLX	SEM ²	1	2	1	2	3	SEM ⁵	Linear	Quadratic	
Intake, g/d													
Forage OM	6,699	7,120	5,904	158.7	0.34	<0.001	6,586	5,915	7,222	120.5	<0.001	<0.001	<0.001
Total OM	6,699	8,324	6,614	161.3	0.001	<0.001	7,187	6,545	7,905	121.7	<0.001	<0.001	<0.001
NDF	5,357	5,925	5,016	127.7	0.48	<0.001	5,251	4,999	5,672	96.4	<0.001	<0.001	<0.001
N	87.1	135.8	101.9	2.17	<0.001	<0.001	116.6	85.4	122.9	1.65	0.002	<0.001	<0.001
Total tract digestibility, % of intake													
OM	67.7	71.0	64.7	0.11	0.17	<0.001	69.5	65.5	68.3	0.09	<0.001	<0.001	<0.001
NDF	73.6	72.9	68.6	0.21	<0.001	<0.001	72.5	70.5	72.0	0.19	0.05	<0.001	<0.001
N	61.4	72.2	66.0	0.43	<0.001	<0.001	70.9	59.6	69.2	0.30	<0.001	<0.001	<0.001

¹Cattle were allowed to graze native range pastures and were allotted to 1 of 3 dietary treatments: grazing only (CON); cracked corn and soybean meal (65.6% cracked corn, 32.7% soybean meal, and 1.7% dried molasses) fed at 0.32% of BW on a DM basis (CRN); or ground flaxseed (98.4% ground flaxseed and 1.6% dried molasses) fed at 0.18% of BW on a DM basis (FLX).

²n = 6.

³Treatment contrasts: 1: CON vs. CRN and FLX; 2: CRN vs. FLX.

⁴Sampling periods: 1 = June 9 to July 7, 2006; 2 = July 8 to August 4, 2006; 3 = August 5 to September 1, 2006.

⁵n = 18.

⁶Sampling period contrasts.

⁷Treatment × sampling period.

Table 11. Effects of supplemental ground flaxseed on the growth performance of steers grazing summer native range on the northern Great Plains¹ (Exp. 2)

Item	Early summer			Late summer			SEM ²	P-value ³				
	CON	CRN	FLX	CON	CRN	FLX		Treatment	Period	1	2	Trt × Pd
BW gain, kg	18.7 ^{d,g,j}	23.1 ^{b,k}	19.4 ^d	12.4 ^{a,f,g,h}	26.8 ^{b,e}	27.6 ^{b,e,l}	1.7	<0.001	0.21	<0.001	0.41	0.003
ADG, kg/d	0.54 ^a	0.66 ^{a,d}	0.56 ^a	0.44 ^{a,e}	0.96 ^b	0.99 ^b	0.06	0.001	<0.001	<0.001	0.47	0.001
G:F	0.074 ^{a,g,j}	0.075 ^{a,g,j}	0.074 ^{a,g,j}	0.051 ^{a,h}	0.094 ^{c,i,k}	0.138 ^b	0.007	<0.001	0.004	<0.001	0.01	<0.001

^{a-c}Within a row, means without a common superscript letter differ ($P < 0.001$).

^{d-f}Within a row, means without a common superscript letter differ ($P < 0.01$).

^{g-i}Within a row, means without a common superscript letter differ ($P < 0.05$).

^{j-l}Within a row, means without a common superscript letter differ ($P < 0.10$).

¹Cattle were allowed to graze native range pastures and were allotted to 1 of 3 dietary treatments: grazing only (CON); cracked corn and soybean meal (65.6% cracked corn, 32.7% soybean meal, and 1.7% dried molasses) fed at 0.32% of BW on a DM basis (CRN); or ground flaxseed (98.4% ground flaxseed and 1.6% dried molasses) fed at 0.18% of BW on a DM basis (FLX).

² $n = 6$.

³Contrasts: Period = early summer = June 9 to July 7, 2006, which corresponds to sampling period; late summer = August 4 to September 1, 2006, which corresponds with sampling period 3; 1 = CON vs. CRN and FLX; 2 = CRN vs. FLX; Trt × Pd = treatment × sampling period interaction.

was likely due to the negative impact fats can have on fiber digestion (Devendra and Lewis, 1974; Jenkins, 1993). This response was likely due to the fact that supplements were only fed once a day. The fat concentration in the rumen was perhaps great enough to cause a brief depression in ruminal fiber digestion and therefore reduce the molar proportion of acetate shortly after feeding, but the response subsided as time after feeding elapsed, which precluded a detection of a reduction in ruminal fiber digestion. The main effects of treatment on the reduction in ruminal total VFA observed in this experiment are in contrast to others who found no difference in total ruminal VFA production in grazing cattle fed corn at similar amounts to those in the current experiment (Pordomingo et al., 1991; Brokaw et al., 2001) or soybean oil (Brokaw et al., 2001). The molar proportions of acetate are similar to those reported by Brokaw et al. (2001), where acetate declined with corn and soybean oil supplementation. Nonetheless, the lack of differences in propionate is contrary to that published by Brokaw et al. (2001) who reported an increase in the molar proportions of propionate, yet is in agreement with Pordomingo et al. (1991) who fed beef cattle grazing summer native rangeland increasing amounts of supplemental grain. Likewise, Leupp et al. (2006) and Krysl et al. (1991) also did not see an increase in propionate when cattle were fed hay and either canola or soybean oil, respectively. The increase in the ruminal molar proportions of butyrate with corn supplementation has also been reported previously when cattle were fed corn (Pordomingo et al., 1991; Hess et al., 1996) or fats (Whitney et al., 2000; Brokaw et al., 2001). The decrease in ruminal pH with CRN was due to the increase in total ruminal VFA compared with FLX. Although there was no difference in ruminal fluid passage rate across treatment, sampling period 2 did have slower fluid passage rate, perhaps due to the lesser quality diet that was consumed at that time based on masticate analysis.

Others have indicated that supplemental energy in the form of carbohydrates either increased (Matejovsky and Sanson, 1995) or decreased (Chase and Hibberd, 1987; Pordomingo et al., 1991) forage intake in grazing cattle. Nonetheless, a change in forage intake was not expected for cattle consuming CRN because it was fed at 13 g/kg of BW^{0.75}, and Horn and McCollum (1987) indicated that concentrates fed up to 30 g/kg of BW^{0.75} typically do not cause a decrease in forage intake. Likewise, a significant reduction in forage OM intake due to flaxseed supplementation was also not expected because the amount of fat fed in these diets was less (1.12, 1.56, and 2.98% total dietary fatty acid for CON, CRN, and FLX, respectively) than that reported to cause a significant decrease in intake (>4%; Schauff and Clark, 1992; Pavan et al., 2007; Scholljegerdes and Kronberg, 2008). Interestingly, no treatment × sampling period interaction was observed in Exp. 1, yet was observed in Exp. 2. Although both experiments were run simultaneously, intake results differed and were likely due to masticate IVOMD values obtained from heifers being used to predict forage intake for steers. Cannulated heifers were of similar age and BW as steers utilized in this study. Nonetheless, Grings et al. (2001) indicated that sex may influence diet selectivity but concluded that physiological stage and age may have a more profound effect on diet selection. Furthermore, values reported by Grings et al. (2001) for in vitro DM digestibility of rangeland from June to Oct rarely differed over the 2-yr experiment between steer and heifer. The treatment × sampling period interaction in Exp. 2 for forage OM intake reflects the greater reduction in intake observed for FLX compared with CON or CRN during sampling period 3 than period 1 or 2. However, during the remainder of the summer grazing season, forage intake for FLX did not differ across treatment. Despite differences in forage quality during the summer grazing season, Brokaw et al. (2001) did not observe any treatment × sampling period interactions when beef heifers

were fed either no supplement or supplemental cracked corn or soybean oil.

Greater ruminal OM digestibility observed for CRN is likely due to the positive associative effects often noted when additional energy and protein are provided to grazing cattle (Horn and McCollum, 1987). This is not surprising given the fact that soybean meal, which has increased content of degradable protein, was a major component of the CRN supplement and according to *in situ* analysis (Mustafa et al., 2003), 67.3% of flaxseed CP is effectively degradable in the rumen. Therefore, the increased duodenal supply of microbial OM was likely due to the increased supply of degradable intake protein from both supplements (Köster et al., 1996).

Ruminal NDF digestibility was not negatively affected by treatment. This was surprising considering that cattle fed CRN had a ruminal pH of 5.89 and a ruminal pH below 6.0 may result in a reduction in cellulolytic activity (Hoover, 1986). However, Russell et al. (1979) suggested that populations of cellulolytic bacteria are reduced when pH ranges from 5.7 to 6.2. Although ruminal pH for CRN was 5.89, this difference may not have been enough to impede ruminal fiber digestion. This may be especially true because the grazing only group (CON) had a pH of 6.01, which is considered low enough to be detrimental to NDF digestibility. Our lack of difference in ruminal fiber digestion with the fat amount used herein is not uncommon when cattle are fed stored forages (Krysl et al., 1991; Whitney et al., 2000; Scholljegerdes and Kronberg, 2008) or high-quality pasture (Brokaw et al., 2001). Nonetheless, Chabot et al. (2008) did report a depression in total tract NDF digestibility when cattle grazing wheat grass pasture were supplemented with tallow to provide 2.78% added dietary fat. The discrepancy between ruminal NDF digestibilities being greater than total tract may be due to marker issues or negative intestinal digestion as reported by Funk et al. (1987).

By design we did not anticipate a reduction in overall forage NDF digestibility with fat supplementation because the amount that was fed in the current experiment (0.18% of BW, DM basis) was similar to that fed by Whitney et al. (2000), which did not alter IVDMD compared with control yet increased feed efficiency (G:F) and ADG. Brokaw et al. (2001) did not observe any differences between corn- and corn-oil-supplemented heifers for total tract OM disappearance but did report differences across sampling period. Fieser and Vanzant (2004) observed a supplement type \times forage maturity interaction with a greater depression in apparent total tract OM digestibility when corn was supplemented to high-quality forages. The treatment \times period interaction observed in Exp. 2 was perhaps due to the greater quality masticate collected during sampling period 3 based on masticate IVOMD being 71.9, 64.6, and 74.5% for sampling periods 1, 2, and 3, respectively. It is not clear why the flax treatment responded negatively to greater quality forages. However, during sampling period 3 total intakes were less for FLX than

CON or CRN. Reduced intake and digestibility during sampling period 2 was reflected in the quality of masticate during this period. A reduction in total tract OM digestibility was greater in cattle fed FLX compared with CON or CRN during period 3 than period 1 or 2. The decrease in forage digestibility during sampling period 3 vs. 1 or 2 may have been due to an overall decrease in forage quality selected by cattle fed flax supplements despite the overall quality of the forage being greater in sampling period 3 compared with 2 (based on forage clipping analysis; data not shown).

The addition of supplement increased the dietary intake of most fatty acids (with the exception of 16:0). This was not surprising considering the fact that corn, despite being less low in fat when compared with flaxseed, did provide additional fatty acids compared with the grazing only treatment. Fatty acid content of the forage was dependent on quality and varied across sampling period. Specifically, forage consumed during sampling period 2 was of the least quality compared with period 1 or 3 based on quality variables reported in Table 1. The quadratic responses observed for all fatty acids identified in the diet suggest that fat content of the forage (% of DM) declined with quality. Limited data exist regarding the fatty acid content of summer forages. Brokaw et al. (2001) reported that summer brome grass pasture also exhibited a quadratic effect on fat content of forage.

Total fatty acid supply to the duodenum increased with the provision of supplement. Not surprising was the fact that this increase was substantially greater for cattle fed flaxseed than corn. The intestinal supply of 18:3n-3, the major fatty acid of flaxseed, was greater for FLX than either CRN or CON. This increase in intestinal supply of 18:3n-3 may be beneficial to cattle destined for entry into the feedlot because n-3 fatty acids have been shown to have immuno-protective properties (Alexander, 1998), which could prove useful when morbidity is increased. Work conducted by Quinn et al. (2008) and Farran et al. (2008) attempted to reduce morbidity in feedlot cattle during the backgrounding phase by supplementing flaxseed, but were unable to report any consistent differences between treatments. Perhaps providing n-3 fatty acid before entry into the feedlot will have a greater impact on reducing morbidity in newly received feedlot cattle. Although dietary intake of saturated fatty acids did not differ between CRN and FLX, duodenal supply did differ. This is due to the extensive ruminal biohydrogenation of unsaturated fats in the rumen (Harfoot and Hazlewood, 1988). To illustrate this further, in the current trial, dietary intake of saturated fats was 31.3 and 35.4 g/d for CRN and FLX, respectively. Duodenal flow of saturated fat was 82 and 223 g/d for CRN and FLX, respectively. Scholljegerdes and Kronberg (2008) reported that 18:3n-3 expressed as a percent of 18:3n-3 intake was extensively biohydrogenated (86%) when cattle are fed forage-based diets. Nonetheless, the duodenal supply of unsaturated fats (MUFA, PUFA, and total unsatu-

rated fat) was significantly greater in FLX than CRN. In addition, the amounts of CLA (18:2*cis*-9*trans*-11) and 18:1*trans*-11, a precursor for CLA, were greater for flax-fed cattle.

Postruminal disappearance for key fatty acids such as 18:2n-6, 18:3n-3, PUFA, and total unsaturated fatty acids were greater for cattle in the current trial than previously reported by our laboratory (Scholljegerdes and Kronberg, 2008). However, the values reported herein are similar to the values reported by others (Wachira et al., 2000; Scollan et al., 2001; Scholljegerdes et al., 2004). Differences in postruminal disappearance of fatty acids in flax-fed cattle and that of our previous work (Scholljegerdes and Kronberg, 2008) is likely due to the processing of the flaxseed. Flax fed in this study was ground, whereas in the previous study flax was fed whole and the seed coat may have offered some protection to the fatty acids and prevented absorption. Price et al. (2007) reported an increase in intestinal digestibility coefficients when safflower seeds were fed cracked vs. whole.

The treatment \times sampling period interaction for apparent total tract OM, NDF, and N digestibility in Exp. 2 was due to apparent changes in the magnitude of differences between treatments throughout the experiment. Specifically during sampling period 3, FLX total tract OM, NDF, and N digestibility remained consistent with previous sampling periods, whereas CON and CRN had an increase in nutrient total tract digestibility. Forage quality was greatest, based on masticate IVOMD, during sampling period 3.

There was a treatment \times sampling period interaction for steer ADG and G:F. As expected, the increase in dietary energy increased total BW gain and ADG compared with unsupplemented cattle. The significant treatment \times sampling period response appeared to manifest itself during the later part of the summer. Specifically, during early summer, cattle fed CRN had greater ADG than either CON or FLX. However, during the late summer, ADG was greater for supplemented cattle, with CRN and FLX performing equally. Interestingly, unsupplemented cattle (CON) performed more poorly during the late summer than early summer. This was in spite of forage being of greater quality. The TDN:CP ratio for masticate collected during the early and late summer was 8.0 and 8.9, respectively. Moore et al. (1999) indicated that a N deficit may be present in forage when the TDN:CP ratio was >7 . The provision of CRN or FLX changed the TDN:CP ratio in the total diet to 6.96 and 6.72, respectively, and thus provided better synchrony of energy and protein.

The provision of supplemental fat did not improve ADG during the early summer. However, when forage quality was greater, during sampling period 3, FLX performed as well as CRN despite a reduction in total OM intake for FLX. This indicated that the energy supplied by the fatty acids was sufficient to compensate for the decrease in forage intake.

The treatment \times sampling period interaction for ADG and G:F was due to CON not differing between early and late summer, whereas ADG and G:F was greater for CRN and FLX during late summer compared with early summer. This lack of growth performance difference was likely due to little difference being observed between total tract OM, NDF, and N digestibility between sampling period 1 and 3 for CON. It is not surprising that supplemented cattle performed better than unsupplemented by design because similar amounts of corn supplement improved performance in beef cattle consuming forages (Vanzant et al., 1990; Pordomingo et al., 1991). In addition, feeding additional fat has increased animal growth performance (Forster et al., 1993; Whitney et al., 2000; Pavan et al., 2007). Greater ADG for carbohydrate vs. fat energy supplements was also reported by Forster et al. (1993) when corn or rice bran was fed to beef steers consuming bermudagrass or ryegrass wheat hay. Feed efficiency was expected to be greater for FLX compared with CRN based on the previous work conducted by Whitney et al. (2000) who fed beef heifers 3% added dietary fat or 10.5% total dietary fat. Likewise, Albro et al. (1993) also observed an improvement in G:F when steers were fed whole soybeans and low-quality hay compared with unsupplemented controls.

In conclusion, forage quality in the current experiment did not differ to a great degree. Therefore it is difficult to make any strong conclusions about what type of energy supplement is most beneficial with varying forage quality. Nonetheless, under the conditions reported herein, a starch-based supplement provided to steers grazing native pasture increased forage intake and ADG when compared with unsupplemented and flax-fed steers in early summer. However, in the late summer when forage IVOMD was approximately 2 percentage units greater and CP was 0.5 percentage units less than earlier in the summer, cattle fed ground flaxseed consumed less forage and gained BW as well as those fed a corn-based supplement. In addition, flax-fed cattle had greater G:F than corn-fed or unsupplemented steers. Therefore, ground flaxseed fed at 0.18% of BW appears to be a viable option as an energy supplement to steers grazing native range.

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